Governance Informatics:
Using Computer Simulation Models to Deepen Situational Awareness and Governance Design Considerations

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Abstract

A growing appreciation for the roles that complex governance networks play in the design and execution of public policies has combined with the advancement of a suite of "meso-level" policy and governance theories and frameworks and the expansion of computational power and capacity to now make it possible to design computer simulation models that provide "governance informatics" to stakeholders. Governance is the means by which an activity or an ensemble of activities is controlled, directed or steered. Governance informatics is predicated on the assumption that by building the capacity to describe governance processes of heterogeneously interacting agents in complex inter-organizational environments, network managers will enhance their situational awareness to adaptively manage the wicked problems surrounding the accountability and performance of inter-organizational governance networks. Policy tool selection and design considerations may also be rendered using governance informatics platforms. In this chapter we define governance within the context of multi-scale, multi-agent interorganizational networks. The critical element of our approach to governance informatics projects is described. These elements include: setting boundary conditions, stakeholder participatory modeling sessions, development of scoping models, ongoing visualization of governance design, development of pattern-oriented, agent-based models and continuous stakeholder engagement. Opportunities and challenges for engaging stakeholders in this work are addressed. Implications for future research and applications are drawn.

In this chapter we discuss how a certain kind of policy informatics, "governance informatics," can deepen our situational awareness of wicked problems and eventually lead to new governance designs. We shall highlight how computational power is being combined with "complexity friendly" theories of policy system and governance networks to derive conceptual and computer simulation models of heterogeneously interacting agents operating within complex inter-organizational environments. Although we believe that governance informatics has use for theory tuning and theory testing, our aim here is focused on the potential role that governance informatics projects play in network management, with implications for those public administrators and policy analysts who work within and around governance networks. We make the case that governance informatics projects can help practitioners work to resolve wicked problems by developing a conscious situational awareness of network structures, policy tool conditions, accountability ties and performance measures that may or may not be present in existing inter-organizational governance networks (Koliba et al. 2011, p.2). A governance informatics approach to research and practice combines elements of network analysis and complexity science with prominent theories of governance and policy implementation.

We illustrate the potential of governance informatics through the use of two examples drawn from our present research and modeling work in the areas of watershed management and transportation planning. Whatever the context, it is important to develop greater "situational awareness" of the roles that jurisdictional boundaries, institutional authorities, interest groups, and governing rules and relationships play in shaping the governance and policy dynamics of a given situation and context. Why do we need information about how these and other governance processes unfold in complex arrangements? Taking an informatics approach, we must raise this question in the context of practical problem solving. Employing an informatics approach to this question pushes us to consider how knowledge of governance arrangements informs decision-making. We may study how actors within a governance network use their existing knowledge of governance arrangements to inform their practice and contribute to the governance of a region. Taken in this context, governance knowledge serves as a pre-existing condition for specific actors within a governance network. The primary objective of the governance informatics approach outlined here lies in the conscious development of this governance knowledge.

The chapter begins with an examination of governance knowledge and its role in deepening situational awareness. We then introduce the "governance network" as the unit of analysis that serves to anchor model development. Critical elements of our approach to governance informatics projects follows. Future considerations and challenges are explored in the final section of the chapter.

Governance knowledge and situational awareness

Governance knowledge lends a measure of "situational awareness" to stakeholders. Pilots, engineers, emergency management professionals, and military strategists have emphasized the importance that situational awareness brings to understanding complex systems. Situational awareness hinges on a combination of systems thinking, the acquisition and filtering of information, and the application of descriptive patterning that may only be developed through extensive experience built up over time. Endsley observes that stakeholders with situational awareness seek to classify and understand the situation around them. They rely on "pattern-matching mechanisms to draw on long-term memory structures that allowed them to quickly understand a given situation" (Endsley, 1995, p.34). Situational awareness, "is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, [and] the projection of their status in the near future" (Endsley, 1987) see 1995). Situational awareness should explain dynamic goal selection, attention to appropriate critical cues, expectancies regarding future states of the situation, and the tie between situation awareness and typical actions (Endsley, 1995, p.34). If we want to operate within a complex and dynamic system, we have to know not only what its current status is, but what its status *could be* in the future, and we have to know how certain actions we take will influence the situation. For this, we need "structural knowledge," knowledge of how the variables in the system are related and how they influence one another (Radin, 2006, p.24).

In the early stages of development, we believe the tools of research and computer simulation modeling are harnessed to stimulate learning, inform planning and design considerations, and develop adaptive management tools and techniques. We consider the value that "governance" knowledge, (e.g. bearing a conceptual understanding of, and an empirical language to describe governance networks) brings to a given situation. Although such knowledge may be employed at the level of smaller scale problems found at more localized levels, (e.g. governance knowledge is likely to be very useful at the level of the individual public administrator or policy analyst), we will discuss how the kind of knowledge culled from governance informatics can be applied at the level of multi-institutional, multi-agent arrangements, involving complex problems that impact regionally-scaled jurisdictions and governance networks.

Governance networks

Within the social sciences, traditional views of governance have hinged on the relatively simple framework of unitary government agencies implementing policy decisions in the most efficient and effective manner possible. It is now widely acknowledged that this simple model does not account for the kind of hybridized governance networks that have arisen as a result of the persistence of wicked problems (Kickert et al., 1997; Frederickson, 1999; Milward & Provan, 2006). Wicked problems lack a definitive formulation, have no stopping rule, rarely have immediate and ultimate tests of a solution, and are often addressed through suboptimal implementation choices (Rittel & Webber, 1973). As the result of a synthesis of the literature pertaining to policy networks (Rhodes, 1997; Kickert et al., 1997), policy systems (Baumgartner & Jones, 1993; Sabateir & Jenkins-Smith, 1993), public management networks (Milward & Provan, 2006; Agranoff, 2007), policy implementation networks (O'Toole, 1990), and governance networks (Sorensen & Torfing, 2005; 2008), we conclude that inter-organizational networks may be characterized as:

- Facilitating the coordination of actions and/or exchange of resources between agents within the network;
- Drawing membership from some combination of public, private and nonprofit sector agents;
- Carrying out one or more policy function;
- Existing across virtually all policy domains and, often times, existing to integrate policy domains;
- Comprising agents from inter-organizational level, although they are also described in the context of the individuals, groups *and* organizations that comprise them; and
- Resulting from the selection of particular policy tools (Koliba, Meek & Zia, 2010, p.??).

We define a governance network as a relatively stable pattern of coordinated action and resource exchanges involving policy actors crossing different social scales, drawn from the public, private or nonprofit sectors and across geographic levels; who interact through a variety of competitive, command and control, cooperative, and negotiated arrangements; for purposes anchored in one or more facets of the policy stream (2010, p.??). Governance network analysis is informed by resource exchange theory (Rhodes, 1997), vertical and horizontal conceptualization of administrative authority (Agranoff & McGuire, 2003), complex systems dynamics (Haynes, 2003), social network theory (Wasserman & Faust, 1994), and an integrated accountability framework previously developed by members of the research team (Koliba, Mills & Zia, 2011).

A.W. Rhodes (1997) was one of the first scholars to deeply consider the relationship between governance and inter-organizational networks, arguing that governance occurs as "self-organizing phenomena" shaped by the following characteristics:

1. **Interdependence** between organizations. Governance is broader than government, covering non-state actors;
2. **Continuing interactions** between network members, caused by the need to exchange resources and negotiate shared purposes; and
3. **Game-like interactions**, rooted in trust and regulated by rules of the game negotiated and agreed upon by network participants.

Governance is, therefore, characterized by the interdependency of network actors, the resources they exchange, and the joint purposes, norms, and agreements that are negotiated between them.

Considerations of network governance leads to an inevitable consideration of the bargaining and cooperative systems of more "horizontally arranged" ties, in addition to the traditional, "vertically oriented" command and control systems of mono-centric government systems (Kettl, 2006, p.491). We argue that mixed-form governance networks may incorporate all forms of administrative authority. Table 1 provides an outline of the variables that may be used as the basis to describe and analyze governance networks as complex adaptive systems. It relies on the basic architecture of networks: nodes, ties and whole network characteristics. A full explanation of each of these variables is provided at length in Koliba, Meek & Zia (2010) and summarized in Table 1.

Table 1: Taxonomy of Governance Networks (Koliba, Meek, & Zia, 2010)

TYPE OF VAR.	VARIABLE	DESCRIPTORS
Agents (Nodes)	Social scale	Individual; Group; Organizational/Institutional; Inter-organizational
	Social sector (organizational level)	Public; Private; Nonprofit
	Geographic scale	Local; Regional; State; National; International
	Role centrality	Central – peripheral; Trajectory
	Capital resources actor provides (as an input)	Financial; Physical; Natural; Human; Social; Cultural; Political; Knowledge
	Providing accountabilities to….	Elected representatives; Citizens and interest groups; Courts; Owners/Shareholders; Consumers; Bureaucrats/Supervisors/Principals; Professional Associations; Collaborators/Partners/Peers
	Receiving accountabilities from…	See above
	Performance/Output and Outcomes Criteria	Tied to policy function and domain
Ties	Resources Exchanged/ Pooled	Financial; Physical; Natural; Human; Social; Cultural; Political; Knowledge
	Strength of tie	Strong to weak
	Formality of tie	Formal to informal
	Administrative authority	Vertical (command and control); Diagonal (negotiation and bargaining); Horizontal (collaborative and cooperative); Competitive
	Accountability relationship	See above
Whole Network	Policy tools	Regulations; Grants; Contracts; Vouchers; Taxes; Loans/loan guarantees, etc.
	Operational functions	Resource exchange/pooling; Coordinated action; Information sharing; Capacity building; Learning and knowledge transfer
	Policy functions	Define/frame problem; Design policy solution; Coordinate policy solution; Implement policy (regulation); Implement policy (service delivery); Evaluate & monitor policy; Political alignment
	Policy domain functions	Health, environment, education
	Macro-level governance structures	Lead organization; Shared governance; Network administrative organization
	Network configuration	Inter-governmental relations; Interest group coalitions; Regulatory subsystems; Grant and contract agreements; Public-private partnerships
	Properties of network boundaries	Open – closed; Permeability
	Systems dynamics	Systems-level inputs; processes; outputs and outcomes

Using this taxonomy we may observe the emergence of certain patterns. These patterns are formed by the properties assigned to actors and the nature of their ties. These actors will likely exist at one or more social scales: as individuals, as groups of individuals, as organizations and institutions, and as inter-organizational networks. Ties will likely be meditated through any number of different institutional rules, regulations and laws that are set in place through the selection of policy tools. Actors will be tied together through a number of different kinds of vertical or horizontal administrative authorities. Across these ties flow resources that can be tracked as flows of financial, social, political knowledge, human, natural or physical capital. We use this architecture to develop patterns in the governance of a chosen network. The process of pattern development begins with early conceptual, scoping models that eventually develop into computer simulation models of selected features of governance network operations. These features are predicated on the governance frameworks described above.

Elements of a Governance Informatics Project

At the heart of the governance informatics projects outlined here lies a series of models that begin with early scoping models and culminate in operational pattern-oriented agent-based models. Miller and Page describe modeling as an, "attempt to reduce the world to a fundamental set of elements (equivalent classes) and laws (transition functions), and on this basis … understand and predict key aspects of the world" (2007, p.40). "Modeling proceeds by deciding what simplifications to impose on the underlying entities and then, based on those abstractions, uncovering their implications" (Miller and Page, 2007, p.65). As we will see below, the critical elements of a governance informatics project are predicated on an ongoing cycle of stakeholder engagement, empirical analysis, and model development. Through this process decisions regarding boundary conditions, model assumptions, pattern identification, and scenarios development are collectively made and owned. The elements of a governance informatics project includes:

1. Clarification of initial boundary conditions
2. Undertaking of participatory modeling sessions with stakeholders
3. Development of early scoping models
4. Visualization of new design considerations and scenarios
5. Construction of pattern-oriented, agent-based models
6. Continuous engagement with stakeholders

Each of these elements is explained below and illustrated with examples drawn from two, ongoing governance informatics projects being undertaken by the authors. In both cases, the projects are incomplete, but far enough along to highlight how a governance informatics project, informed through active participation with stakeholders and predicated on a process of model development that begins with initial scoping designs and eventually moves into computer simulation models through which alternative scenarios and design considerations may be rendered.

The first case is centered on the transportation planning process undertaken by one northeastern state. This body of work commenced with an initial interest in studying how regional transportation planning networks work and morphed into a full scale implementation of the process described herein. Several published pieces and conference presentations have highlighted this work (cite).

The second case is centered on the persistence of a "wicked problem:" the continued degradation of the water quality of Lake Champlain. The opportunity to undertaken this work was facilitated by the writing and eventual awarding of an NSF EPSCoR grant. Due to the relative newness of this award, no published materials have been presented on this project to date.

In both cases most of the features of the process outline in this chapter have been followed or are in the process of being followed. As we describe elements of the governance informatics projects, we will illustrate using one or both of these examples.

Initial boundaries conditions

Boundaries have been widely recognized as important parameters within virtually any policy or governance network (Kettl, 2006). Determining the boundaries of the network to be modeled is shaped by a number of conceptual and practical constraints. These conceptual constraints concern the limitations of our theories and methods to model observed patterns. Practical constraints concern the limitations that exist around the availability of data and the sheer complexity of the network. These constraints give rise to uncertainty.

Determining the boundary conditions of the network to be modeled are of practical importance when determining the endogenous features of the model. Efforts are made to expand the boundary of the network to be modeled to capture the optimal level of endogenous features.

The boundaries of the system must also be formed in such a way as to capture the imaginations of stakeholders. Governance networks will need to be defined by their functionality. A governance informatics project will be constructed around a common, shared policy domain (transportation, water) and along a very specific functional lines (project prioritization, policy selection). This is why the governance networks we model are defined by their functionality. In the case of our two examples: regional transportation planning networks and regional watershed governance networks.

The transportation planning project is predicated on the processes undertaken by federal, state, regional and local governments to scope and prioritize transportation projects that are eligible for federal funding. The boundary conditions of the network are limited to the explicit processes used to scope and prioritize transportation projects. The challenges to constructing the boundaries of the system in such a way lies in the tacit processes that unfold—often described by stakeholders as the political elements of the process. Capturing the role that political dynamics plays in determining model outputs is, and will continue to be, a perennial challenge to model builders. This is a matter that we will return to at the end of this chapter.

The watershed management project involves a wider array of stakeholders and it constrained by some of the natural science and policy objectives set up within a grant application. The wicked problem to be addressed concerns the nutrient loading that is flowing into Lake Champlain from farms, households, sewage treatment plants, and stormwater run off. Our team is focused on mounting a governance informatics projects within the context of a wider study of the geomorphic dynamics influencing the problem. By working with stakeholders at all levels of jurisdiction and interest we have set the initial boundary conditions around the governance network that is responsible for improving the water quality in the region's lakes and rivers. The output of this regional watershed governance network are the range of policies created and put into practice to modify human behaviors. The range of incentives and regulatory policy tools being considered serve as the boundary objects around which the governance network coalesces. Because of the larger scale and better resourced capacity of the larger project, we are able to build into the models a wider array of endogenous factors that include:

the geomorphology of a changing landscape and dynamic hydrological cycle, as well as the anticipated changes wrought by climate change (to be modeled by another team doing regional climate model downscaling).

Participatory modeling with stakeholders

Initially, stakeholders in the governance network under consideration are invited to participate in the governance informatics project in several different ways: as co-producers of model uses and outputs; as sources of information about the network being modeled; and as validity checks on the robustness of the model as it pertains to its face validity. A critical feature of participatory modeling lies in the collaborative development of storyline or scenarios that will be used for pattern identification (van den Belt, 2004). These sessions are organized at various stages of the project, and designed and facilitated to build the capacity of modelers and stakeholders to work together to translate empirical and simulated data analysis into useful informatics to ground decision making upon. The modeling sessions are supplemented with stakeholder interviews, focus groups and surveys. As model development moves from conceptual to computational phases, stakeholders are invited to offer feedback and provide substantial input into the range of scenarios that are generated from working models. This process allows, "knowledge to emerge and be used throughout the course of an interactive analytic process. Consequently, it can provide a bridge for moving from deductive analysis of closed systems, to interactive analytic support for inductive reasoning about open systems where the contextual pragmatic knowledge possessed by users can be integrated with quantitative data residing in the computer (Bankes, 2002, p.7264).

In the transportation planning project, two initial focus groups were convened comprised of stakeholders ranging from regional Federal Highway Administration officials, congressional staffers, state legislators, metropolitan planning organization staff, MPO board members and town planners participated in this process. In follow up, meetings were held with representatives from the state department of transportation to lay out the potential uses of the POABMs to be developed.

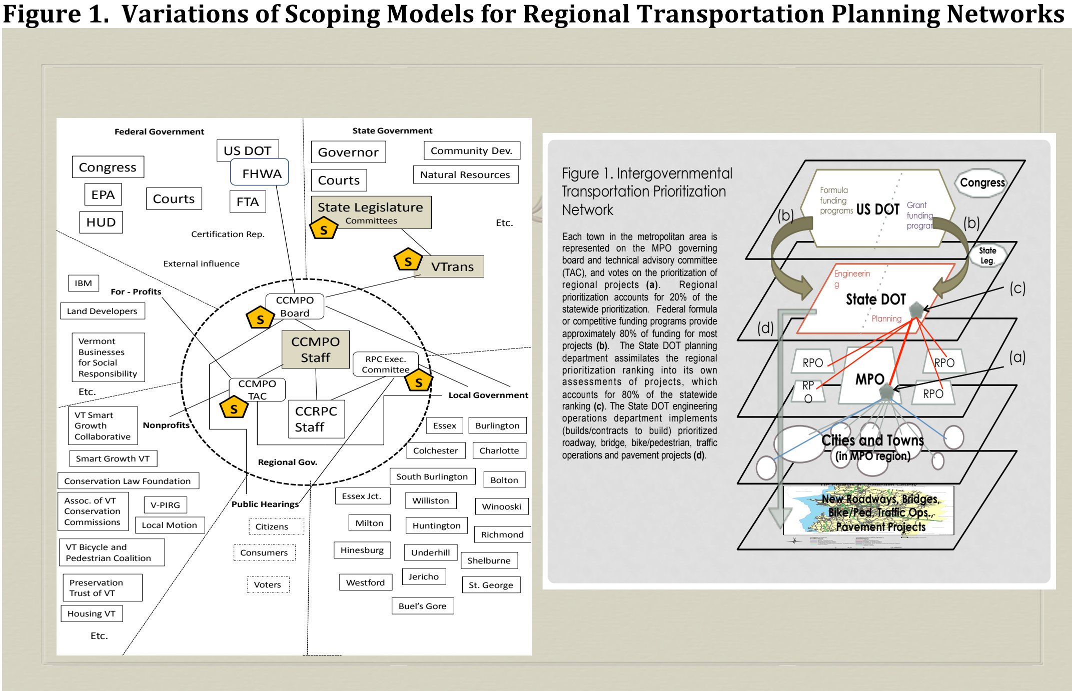
In the watershed management project, a series of informational meetings are being convened with different stakeholder groups. Relying on source document analysis, interviews and observations of public meetings the initial scope model of the governance network has been constructed. Further participatory modeling sessions are planned in the coming years.

Scoping models

Conceptual or scoping models are devised during the very early stages of the project (van Den Belt, 2004). These early models are determined as a result of stakeholder engagement (via traditional research collect methods and participatory modeling sessions) and through the use of theoretical frameworks devised to describe governance networks functioning. The goal of these early scoping models lies in increasing mutual understanding, not in making attempts to make predictions. Initial scoping models are refined as data is collected and analyzed. Once the initial conditions are set, a prolonged and extensive study of the networks to be modeled is undertaken. We have integrated observation and analysis of source documents, existing databases, focus groups, interviews, surveys, legal reviews and participant observations into our initial conceptual, scoping model development.

Below in figure 1, we show two different iterations of the early scoping models for the regional transportation planning network.

Figure 1. Variations of Scoping Models for Regional Transportation Planning Networks

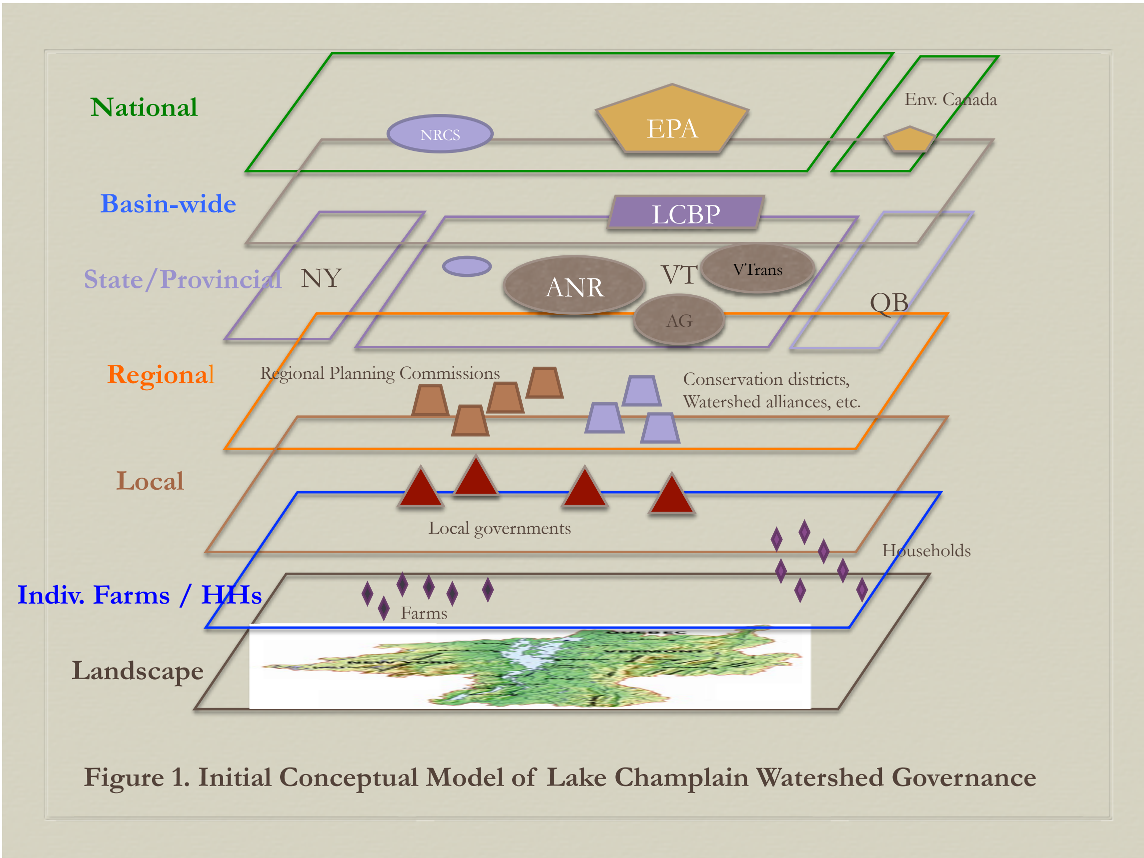


The earlier model on the left separated network actors in sectors (public, private and nonprofit), and further divided the public sector down by level of jurisdiction (local, regional, state and national). The pentagons were identified as "action arenas" (Ostrom, 2005) within which critical decision-making was thought to be made.

A later version of this scoping model on the right places these actors on plains distinguished by their levels of jurisdiction. Following extensive data collection and discussion with stakeholders, it became apparent that transportation planning was driven mostly by dynamics set in place by the state department of transportation. Action arenas are still denoted by the pentagons. These models have been used to visualize how the network is currently configured.

Figure 2 shows the initial scoping model of the watershed governance network for the region. This model is arranged like the latter transportation planning model, with plains denoting levels of jurisdictions. The critical action arenas for this network are also signified by the pentagons.

Figure 2. Scoping Model of Regional Watershed Governance Network



In both of these instances, we identified these action arenas as the veritable "brains" of these networks. The individual people who populate these action arenas and the tools and decision heuristics that governance these spaces become essential features of the pattern-oriented, agent-based models.

Visualization of governance network dynamics

As scoping models are devised, refined and translated into pattern-oriented, agent-based computer simulation models they are used to inform learning and facilitate exchange between modelers and stakeholders. It is possible to stop at the scoping model phase and use these models to engage in any number of different empirical and "governance design" questions. Some of these questions include:

- What capital resources, types of ties, policy tools, administrative strategies, accountability structures, and performance management systems need to be in place to ensure that networks function properly?
- Which actors should be involved in a governance network? When should we attempt to enter into a governance network?

- What to do about the governance networks we are already operating within?
- What is our role within this governance network? Does my organization understand that I'm participating in the network on its behalf? Do I have adequate resources to
- To whom is the network accountable? When should we actively seek to alter the accountability structures of our own organizations in order to pursue network-wide goals? How do we manage to handle accountability trade-offs? Accountability couplings? What kinds of skills and strategies are needed to operate within a hybridized accountability regime?
- How is network performance defined? Who is doing the defining? How is network performance measured and managed? Where within the governance network is network performance data discussed, used to make decisions? And acted upon?
- Is it possible to design a governance network? What are the few "simple rules" that set governance network activity in place?

We have had success at guiding graduate students in devising these scoping models and using these models to make recommendations to actors within governance networks of many different forms and functions. As analytical tools, these scoping models can be used in classroom, workshop, and participatory modeling sessions to guide reflection and critical thinking. Koliba et al. (2010) provides an overview of how to undertake these models in a generative, learning-centered way.

To date, the scoping models presented in figures 1 and 2 have been introduced to stakeholder groups during early modeling sessions. These models serve as boundary objects around which deeper examination of the networks unfolds. Lines are drawn between actors, the meaning of these ties are discussed, and further models are refined. New avenues for alternative designs are considered.

Pattern-oriented, agent-based models

The capacity of computer models of complex governance networks to lead to accurate forecasting and prediction of particular policy outcomes is predicated on a "deep uncertainty" that characterizes our current state of understanding of complex social systems. Bankes (2002) characterizes this deep uncertainty arising as, "the result of pragmatic limitations in our ability to use the presentational formalisms of statistical decision theory to express all that we know about complex adaptive systems and their associated policy problems" (p.7263).

To cope with the inherent complexity and uncertainty in the social complexity of governance networks, we undertake a variation of "pattern-oriented" modeling." Pattern-oriented models are described by Grimm et al. as "bottom-up" models that emphasize the applicability of models to real problem solving (2005, p.987).

Grimm et al. describe pattern-oriented models this way:

> In [this approach to modeling], we explicitly follow the basic research program of science: the explanation of observed patterns. Patterns are defining characteristics of a system and often, therefore, indicators of essential underlying processes and structures. Patterns contain information on the internal organization of a system, but in a "coded" form. The purpose of [pattern-oriented models] is to "decode" this information… A key idea [in these models] is to use multiple patterns observed in real systems to guide design of model structure. Using observed patterns for model design directly ties the model's structure to the internal organization of the real system. We do so by asking: What observed patterns seem to characterize the system and its dynamics, and what variables and processes must be in the model so that these patterns could, in principle, emerge?" (p.987)

Pattern-oriented approaches are pursued because they help to focus and reduce the uncertainty found in any model of a complex adaptive system. Grimm et al., add that,

> [Pursuing a pattern-oriented] strategy is a way to focus on the most essential information about a complex system's internal organization. Multiple patterns keep us from building models that are too simple in structure and mechanism, or too complex and uncertain. Using patterns to test and contrast alternative theories for agent behavior or other low-level processes is a way for [modelers] to get beyond clever demonstration models and on to rigorous explanations of how real systems are organized and how they respond to internal and external forces. (p.99?).

The patterns of governance are established during the scoping model development stage and refined as the computer models are being developed. The challenge that fuels the complexity of governance networks is that we must make selective choices about the basic building blocks of these patterns. Pattern select will need to be grounded in some material substance: real people, institutions, resource exchanges and data. In the case of social systems, these material substances are individuals, groups and individuals, and organizations, the nature of the ties that bind them, and the existing, reified rule structures in place to shape these dynamics. The current and growing body of theories and frameworks that are being devised to describe and evaluate governance networks may provide social scientists with guidance around how best to organize the models. For a deeper examination of the theoretical issues pertaining to this matter, see Koliba & Zia, (2012).

Grimm et al. note that the value of the frameworks we use to describe patterns will need to possess some measure of realism relative to the observed phenomena. "The realism of structure and mechanism of pattern-oriented models helps parameters interact in ways similar to interactions of real mechanisms. It is therefore possible to fit all calibration parameters by finding values that reproduce multiple patterns simultaneously." This technique is known as ''in- verse modeling'' (p.98?).

Grimm et al. describe the process of developing pattern-oriented, agent-based models (POABMs) in the following way:

1.) Alternative theories of the agent's decisions are formulated;
2.) Characteristic patterns at both the individual and higher levels are identified;
3.) Alternative theories are then implemented in a bottom-up model and tested by how well they reproduce the patterns;
4.) Decision models that fail to reproduce the characteristic patterns are rejected;
5.) Additional patterns with more falsifying power can be used to contrast successful alternatives. Rigorous techniques can be used to design experiments and analyze data. (p.98??).

The method for simulating these bottom-up patterns most often associated with pattern-oriented approaches is agent-based modeling (ABM). ABMs of social systems are predicated on bottom-up dynamics originating from the actions of individual agents—most often individuals that operating in a nested social complexity: individuals forming groups, groups forming organizations, organizations forming interorganizational networks. By using ABMs, "… agents are *not* usually viewed as fully rational utility maximizers who behave independently of each other, but rather as adaptive agents who are context dependent and follow heterogeneous threshold preferences…" (North & Macal, 2007, p.2). These threshold preferences may be described as the "decision heuristics" of network agents (North & Macal, 2007). ABMs have been shown to be an effective means of modeling the types of emergent behaviors, structures, functions and actions that occur as a result of bottom-up dynamics.

It needs to be noted that a critical dimension of POABMs lies in the calibration and verification of model parameters and outputs. Although we believe that devising toy models or entirely theoretically-driven models has a role to play in governance informatics projects, the power of POABMs lies in their capacity to be calibrated to observed patterns. The validity of these models, be it face validity in the eyes of stakeholders or construct validity in the eyes of other scientists and peer reviewers is critical.

Space precludes a detailed account of the two POABM developed for the transportation and watershed management cases. In the case of the transportation planning network, the scoping models presented in figure 1 were supplemented with other artifacts that are used by the network to prioritize projects. Table 2 presents the multi-critical analysis framework used by this network to prioritize transportation projects. The weights assigned to each class of transportation project are displayed in this table.

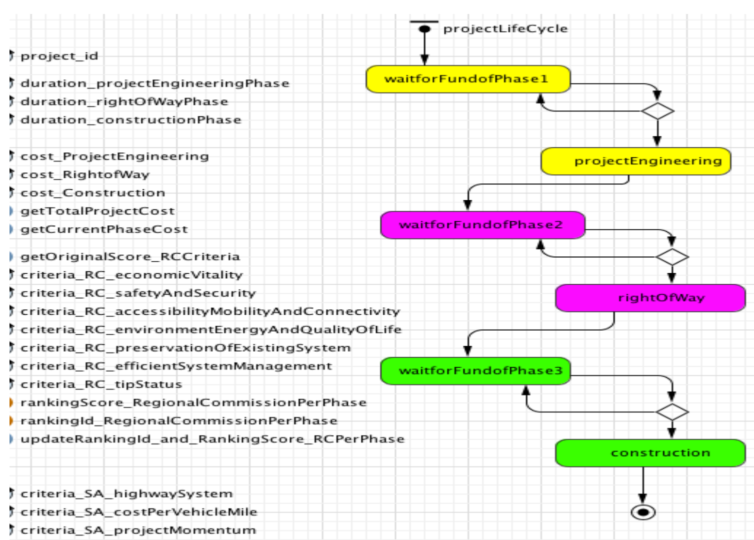
Table 2. Multi-Criteria Analysis Framework for Transportation Project Prioritization

	State Level		Regional Level			
	SDOT Criteria		Chittenden County		Other Counties	
Project Class		**Wt.**	**MPO Criteria (applied across all classes)**	**Wt.**	**RPC Criteria since 2006**	**Wt.**
Roadway	Highway system*	.40	Economic vitality Safety and security Accessibility, Mobility and connectivity Environment, Energy and Quality of life Preservation of Existing System Efficient System Management	.166 @	The impact of the project on congestion and mobility conditions in the region The availability, accessibility and usability of alternative routes The functional importance of the highway or bridge as a link in the local, regional or state economy The functional importance of the facility in the social and cultural life of the surrounding communities. Conformance to the local and regional plans Local support for the project.	Ranked by priority from 1 (being the highest) to 5 (being the lowest)
	Cost per vehicle mile*	.20				
	Regional priority	**.20**				
	Project momentum	.20				
Paving	Pavement condition index*	.20				
	Benefit/cost*	.60				
	Regional priority	**.20**				
Bridges	Bridge condition*	.30				
	Remaining life*	.10				
	Functionality*	.05				
	Load capacity and use	.15				
	Waterway adequacy & scour suscept.	.10				
	Project momentum	.05				
	Regional input and priority	**.15**				
	Asset-benefit cost factor	.10				
Bike/ Pedestrian	Land use density	.20				
	Connectivity to larger bike/ped network	.10				
	Multi-modal access	.05				
	Designated downtown/village center	.05				
	Project cost	.20				
	Regional priority	**.20**				
	Project momentum	.20				
Traffic operations	Intersection capacity*	.40				
	Accident rate	.20				
	Cost per intersection volume*	.20				
	Regional input and priority	**.20**				
	Project momentum	.10				
Park and ride	Total highway and location*	.40				
	Cost/parking space	.20				
	Regional Input priority	**.20**				
	Project momentum	.20				

***denotes Asset Management System**

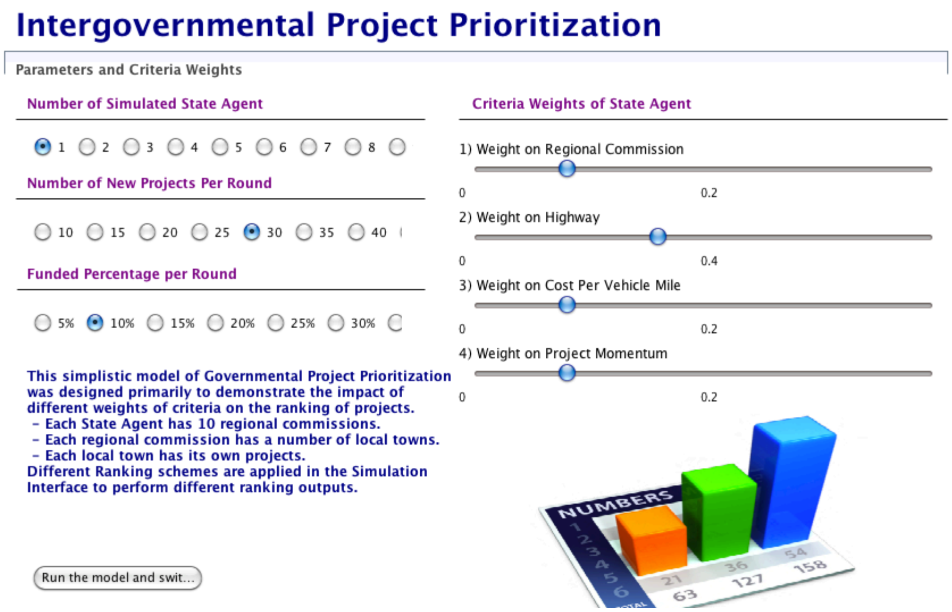
Zia et al. have used these weights to develop calibrated models of the transportation project prioritization process. Figure 3 below shows the state chart of the discrete path that project selection and financial resource allocation takes place.

Figure 3. State Chart for Transportation Project Prioritization POABM



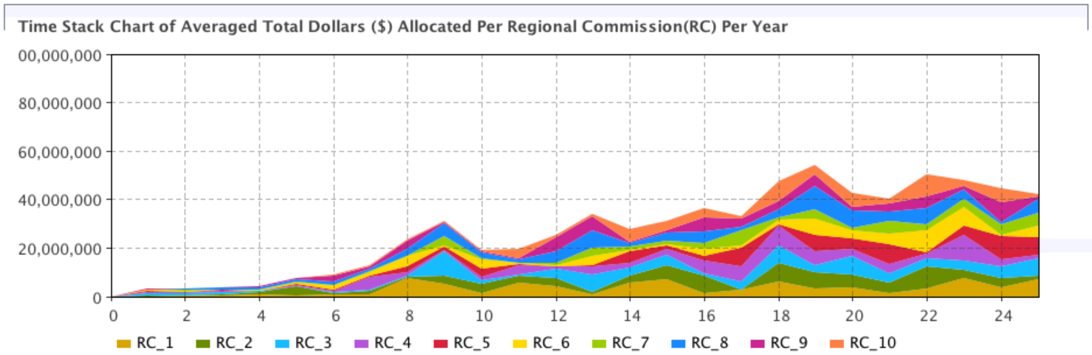
By developing agent-based models using the institutional actors as agents, we are able to render a close approximation of the funding patterns across the ten regions of the state. Figure 4 below shows a screen shot for the user interface for the model.

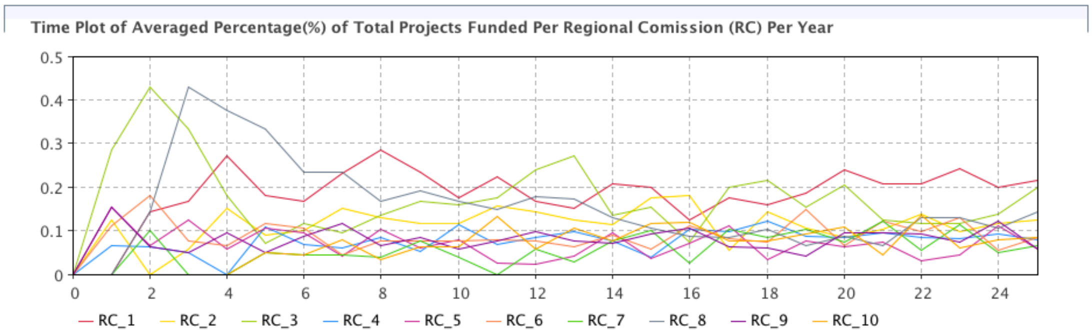
Figure 4. Screen Shot of Transportation Project Prioritization POABM

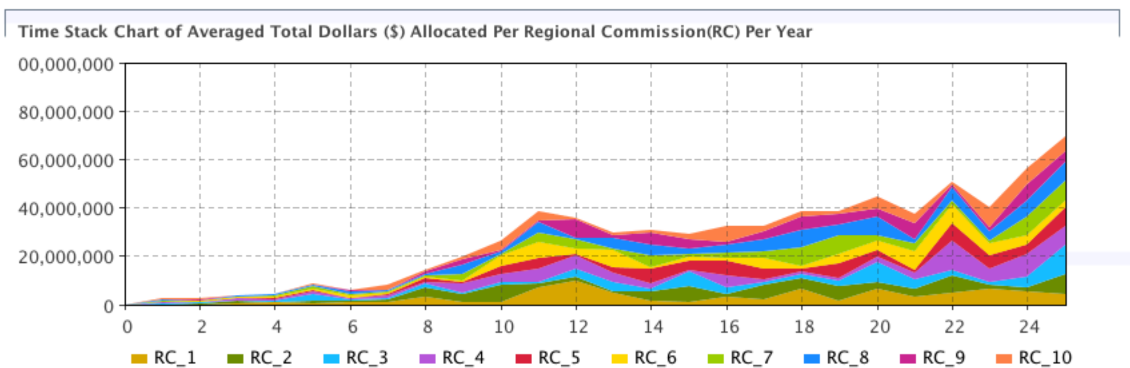


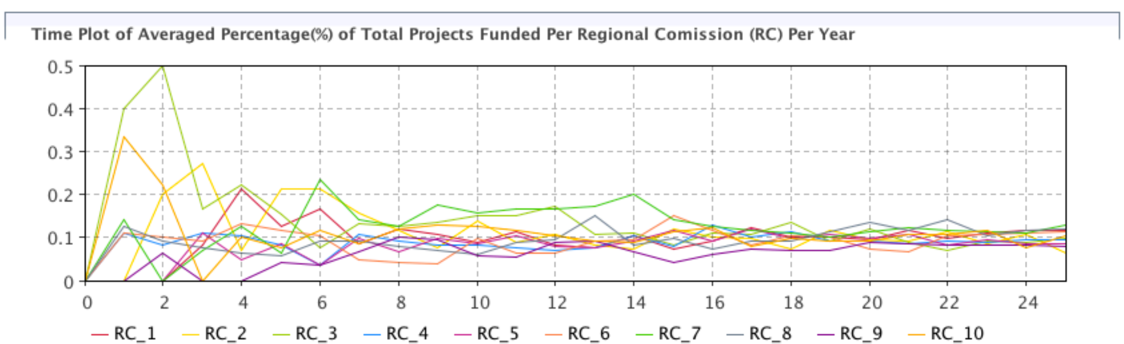
Prior funding patterns and project score between the years of 1998 to 2011 were used and calibrated in this model. Figure 5 (a) provides a graphic display of funding patterns given pre-existing decision heuristics and scoring patterns. Figure 5 (b) demonstrated what these funding patterns would look like if a new scenario: regions are given more authority to dictate which projects in their region are funded. This is accomplished by moving slider (1) (see above) from 0.2 to 0.4.

Figure 5. Scenario Runs for Transportation Project Prioritization POABM



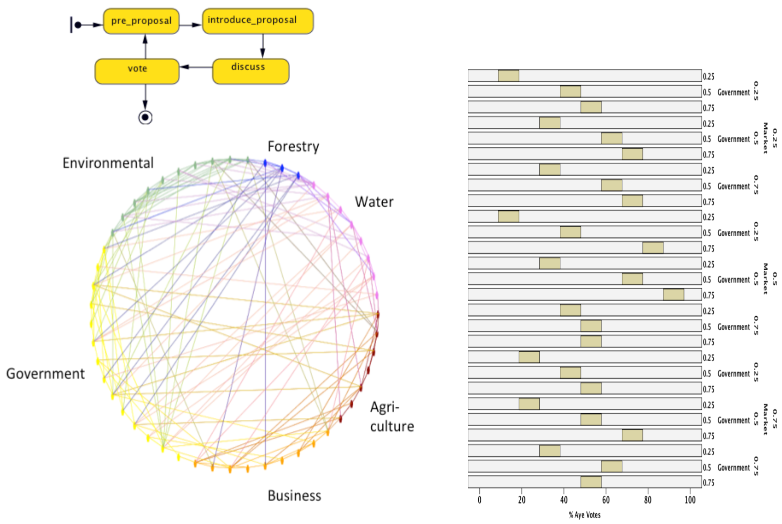






The example of pattern-oriented agent based models for the watershed scoped in figure 2 is still under construction. However, in a POABM devised by Zia et al. of a watershed partnership in one southern state, an agent-based model of the steering committee for the partnership was devised. Figure 6 below illustrates a "small world" configuration of the ABM, with different stakeholder groups ringing the action arena. The decision heuristics of each agent were calibrated using interview and survey data collected from each, real world, actors.

Figure 6. Watershed Partnership POABM, Selected Features



To run experimental simulations, project proposals were provided weights depending on the economic, government or environmental goals attained in each proposal. Each proposal would be rated on a scale of 0.0 to 1.0 relative to its level of attainment of each type of goal. The results of this model suggest that agent heterogeneity had a positive effect on reaching majority opinions around projects.

Continuous stakeholder engagement

Squazzoni and Boero (2010) suggest that our goal in projects of this nature lies not putting ourselves in the position, "to predict the future state of a given system, but to understand the system's properties and dissect its generative mechanisms and processes, so that policy decisions can be better informed and embedded within the system's behavior, thus becoming part of it" (p.3). The very process of providing feedback concerning a system's dynamics back to the system itself becomes an important component of decision making and action. "Once viewed as something that is embedded within the system, rather than taking place before and off-line, policy [and governance] starts to be practiced as a crucial component that interacts with other components in a constitutive process" (Squazzoni & Boero, 2010, p.3). Thus, knowledge and information regarding network governance processes may be fed into the communication systems of the network, facilitating system-wide learning, adaptation, and the emergence of new strategies (Guney & Cresswell, 2010).

The pattern-oriented, agent-based models (POABMs) of governance networks presented here can be used, "when policy makers need to *learn from science* about the complexity of systems where their decision is needed," as well as "when policy makers need to *find and negotiate certain concrete ad hoc solutions*, so that policy [and governance] becomes part of a complex process of management that is internal to the system itself" (Squazzoni & Boero, 2010, p.6).

In both of the examples used to illustrate the governance informatics projects, ongoing stakeholder engagement is being undertaken. Resources have been secured to engage in follow up modeling sessions, with the practical utility of still a subject of scrutiny.

Looking forward: Challenges and opportunities

The deep uncertainty that persists within the models being devised in these and other projects is still very real. We may characterize the challenges to undertaking such endeavors along the following lines:

1.) **Challenges associated with determining boundary conditions.** It was been widely noted how public problems, policy goals and even policy solutions are mediated through socially constructed frames (Stone, 2002). One person's problem frame may be another person's solution frame. Determining the functional characteristics of the governance network to be modeled may, therefore, be contested. Sources of funding for projects like these and the prior dispositions of modelers will likely shape how initial boundary conditions are set. The decisions regarding which parameters are endogenous and which parameters are exogenous to the models are, in the end, subjective or predicated on the constraints placed on data availability and theoretical exhortation. We believe that some of these challenges may be overcome as the number of examples of governance informatics projects increase and valuable lessons are learned and disseminated.

2.) **Challenges associated with recruiting willing stakeholders to participate in the project.** Admittedly, we have faced some resistance from some stakeholders in the transportation planning network who initially questioned the efficacy of undertaking the process. Questions surfaced concerning the uncertainty associated with models of this nature. Some stakeholders appeared to possess a limited understanding of why a deepened situational awareness of governance dynamics is desirable. We believe that these two outlooks will be modified with the advancement of more models and examples. Perhaps a more structural challenge associated with stakeholder involvement in governance informatics projects concerns some of the real power disparities that surface when governance networks are modeled. Some will likely be advantaged by having stakeholders deepen their situational awareness of the governance dynamics. Others will become disadvantaged and, anticipating this, decline participation.

3.) Challenges associated with the availability of data. We believe that by collaborating with stakeholders we put ourselves into a better position to gain access to critical sources of data. With the rise of computational power and the advancement of information technology, more and more data will be made available, suggesting to some that we have enter the era of "big data." Determining how to best to use data and select data to inform models becomes an important consideration. Realistically, those engaged in the kind of governance informatics projects described here will need to scale up or down their expectations on what a given model can deliver depending on the availability of data. Identifying and then negotiating access to sources of data have been a major issue arising in both the transportation and watershed projects discussed here.

4.) Challenges associated with model validity. In a recent publication we discussed the matter of model validity and verification in depth and replicate our assertions below:

> The level of systemic error that is possible in computer simulation models [of governance networks] can potentially be quite large. Modelers refer to this as "noise" in the model. Although efforts can be made to reduce the noise of a model, the propensity for large systemic error virtually assures us that the error rates of simulation models of social systems far exceed levels of statistical significance found in more linear regression models. We are mindful of why these error rates may be higher in social systems, than they are in the more predicable (but still uncertain) areas of natural and biological systems. Social agents maintain a certain level of autonomy in most social systems. The capacity of individual social agents to exert their own free will inevitably lead to a certain level of unpredictability. Agent based modelers account for this unpredictability in ascribing probability functions to agent behavior that are, ideally, calibrated to empirical observations. Modelers must still make a wide range of choices in building their models, as they are boundedly rational as well. They make choices around what elements to incorporate into the model and should be prepared to defend those choices (Koliba and Zia, 2012, p.?).

The opportunities that are available to modelers and stakeholders looking to use our increasing computational power to develop deeper situational awareness of the existing governance dynamics are growing, as evidenced in the examples provided throughout this book. By undertaking governance informatics projects through early stages of boundary setting and stakeholder engagement, to the middle stages of developing scoping models and collectively learning from these early conceptual models, to the more advanced stages of running alternative scenarios, we believe that there are many points of entry to legitimate the investment of time and resources into projects of this nature.

Our experiences of sharing and using scoping models as boundary objects to work with stakeholders and describe the opportunities available through deepened governance knowledge and situational awareness suggest that there is a great value in undertaking these projects to this stage of development. As our POABMs are refined and used to inform participatory modeling sessions, we believe the value of these models to inform real world decision making and policy and governance designs will bare out. We are working with third party evaluators to judge the efficacy of these governance informatics projects and will report on those findings in the years to come.

The ambitions that underlie these kinds of governance informatics projects are mediated through these instances of quick feedback that are found in the ah-ah moments that surface during meetings between modelers and between modelers and stakeholders. The larger contributions that POABMs bring to the areas of theory testing and theory tuning remain to be seen. Although we have chosen not to highlight how the role that hypothesis testing will inform these projects, we are actively engaged in theory testing and tuning and discuss the issues and possibilities for theory testing and tuning elsewhere (Koliba and Zia, 2012).

Conclusion

Several trends are shaping the landscape of policy informatics that are addressed in other chapters of this book. The rise of computational power, the growing availability of big data sets, the advancement of ABM and other hybrid modeling approaches, and the growing appreciation of "complexity friendly" theories that already exist within the public administration and policy studies fields, contribute to our optimism regarding our deepened capacity to model governance networks.

The need for more governance informatics has, arguably, never been greater. The persistence of wicked problems, the challenges associated with the complexity of the problems involving matters of geographic and jurisdictional scale, and the role of individual free will and political dynamics are not going away. The situational awareness that we believe is possible through attempting to understand and eventually harness this complexity is worth pursing. We hope that methods and approaches outlined in this chapter are only the tip of a proverbial iceberg, signifying a new phase in computer simulation modeling of social phenomena, and perhaps more importantly, building the capacity to harness these models to serve the public good.

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